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stars, two of which have spectra with poorly defined lines, afford no evidence in opposition to this theory.

The spectra of twenty-three other stars in the same region of the sky have been observed with the Mills spectrograph, but none of them show speeds in the vicinity of $+38^{\text{km}}$, with the possible exception of two or three having variable velocities.

THE NORTHERN LIMIT OF THE ZODIACAL LIGHT.¹

BY E. A. FATH.

The boundaries of the zodiacal light are hard to determine because of the faintness of the phenomenon, although the light along the axis is quite strong and can be seen even in cities in spite of the electric illumination. From the usual observations of the boundaries of this light we should expect the light to extend about 20° to the north and south of the Sun. That the zodiacal light is of much greater extent is evident from the observations described below.

In the summer of 1907 Director CAMPBELL, of the Lick Observatory, called the writer's attention to a faint light, which for years has been seen in the summer by various observers at Mount Hamilton, extending along our northern horizon near midnight, and asked that an attempt be made to determine its character. Observations were accordingly begun and continued during the summer of 1908.

The general appearance of the phenomenon when observed near midnight, with a clear sky and no Moon, is that of a flat arch of light with its maximum intensity near the north point of the horizon. At that time of night in the early part of July, 1908, the greatest altitude above the northern horizon was 18° . It extended westward about 40° and eastward to the Milky Way, and was symmetrical with respect to the meridian. At the extremities it was only a degree or two above the horizon, depending on the clearness of the air at such a low altitude. When, however, the observations were

¹ For a complete account see *Lick Observatory Bulletin*, No. 142.

made before midnight the maximum was always to the west of the north point, and after midnight always to the east.

Three hypotheses as to the origin of this light in the north seemed to require examination: 1. That it is an aurora; 2. That it is twilight; and, 3. That it is the zodiacal light. These hypotheses will now be examined.

The aurora hypothesis is not satisfactory for three reasons: 1st. The light is seen only in the summer, during a period of about two months on either side of the summer solstice. 2nd. Observations made with a spectroscope on several evenings showed the aurora line, λ 5571, to be visible in all parts of the sky, and no brighter when the spectroscope was pointed to the maximum of the luminous area than when pointed many degrees away and entirely outside it. 3rd. Observation shows that the maximum of the light moves with the Sun.

If the light were twilight it seems reasonable to suppose that the mean of the observations would show the maximum intensity to be on or very near the vertical circle passing through the Sun. The mean of twenty-nine observations, taken from June 27 to August 27, 1908, places this maximum $1^{\circ}.7$ farther east along the northern horizon than this vertical circle. Moreover, an observation taken at midnight on July 2d shows that the light could be seen 46° north of the Sun. It has usually been stated that twilight ceases when the Sun is 18° below the horizon. At the time of this observation the Sun was 30° below the horizon, and thus 12° lower than the twilight limit. In order to test the question as to the duration of twilight quite a number of observations were made during the summers of 1907 and 1908. They agree in placing the Sun very close to 18° below the horizon at the close of twilight in the evening or the beginning of dawn in the morning. The twilight hypothesis, therefore, does not explain the phenomenon satisfactorily.

Of the three hypotheses that of the zodiacal light remains.

Observations on seven nights showed a direct connection of this light and the ordinary cone of the zodiacal light, a practically straight line forming the northern boundary of both the cone and the light under observation. During the summer months the zodiacal light can readily be seen at Mount

Hamilton, both in the west in the evening and in the east in the morning. The connection was seen with both the eastern and western cones.

The $1^{\circ}.7$ displacement, referred to above, of the maximum of the light to the east of the vertical circle passing through the Sun appears significant. If we assume the axis of greatest intensity of the zodiacal light to be in or near the ecliptic, then at midnight at the time of the summer solstice the axis will be perpendicular to the vertical circle passing through the Sun. Before midnight the western angle between the axis and the vertical circle will be less than 90° , and after midnight the eastern angle will be less. In general, before the summer solstice the western angle will average less throughout the night than the eastern, and *vice versa*. Now, taking two points at the same altitude and symmetrically situated with respect to the vertical circle, the one to the west would average nearer the axis throughout the night for observations before the solstice, and therefore be the brighter. In the same way, after the solstice, the eastern one would be the brighter. We might expect, therefore, that before the solstice the maximum observed intensity would be shifted toward the west and after the solstice toward the east, the shift varying with the distance of the Sun from the solstice. Now we find an observed displacement of $1^{\circ}.7$ toward the east, and all the observations upon which this observed displacement depends were made after the solstice. The observations also show a tendency for the displacement to increase with the time. The observations thus agree with the hypothesis.

Another test was then applied. It was found that if the point of greatest altitude was connected with the point of greatest eastern or western extent, and continued until it intersected the ecliptic, these intersections were located from 40° to 105° from the Sun. On plotting the results it was seen that the light was distributed fairly symmetrically with respect to the Sun. It passes 46° to the north and intersects the ecliptic about 70° on either side. This applies, of course, only to the part north of the ecliptic. Assuming symmetry with respect to the ecliptic also we have the lenticular appearance of the zodiacal light. The effect of atmospheric absorp-

tion would be to bring the intersections too close to the Sun. The apex of the zodiacal light cone can be seen at various distances from the Sun ranging from 40° to over 100° . This agreement between the observed position of the apex and the position of the intersections is as satisfactory as can be expected from the nature of the objects observed.

The observations were then used in another way. The northern boundary of the cone of the zodiacal light had been located with reference to the stars. This boundary was then located on a celestial globe and extended until it intersected a great circle passing through the Sun and perpendicular to the ecliptic. The mean of fourteen observations of this kind showed that we should expect the zodiacal light to pass 42° north of the Sun. Observations above the northern horizon give 46° .

The writer also examined the observations of JONES,¹ and found that by extending JONES's boundaries of the zodiacal light they would in many cases exceed latitudes of 45° both north and south of the Sun.

From the evidence at hand it seems fair to conclude that the phenomenon observed is the zodiacal light, and that therefore its northern boundary, as seen from the Earth, can be traced 46° north of the Sun, and in consequence the zodiacal light is much greater in extent than has usually been supposed.

In conclusion, it should be stated that as early as 1840, HERRICK,² of Yale University, thought he had evidence that he could sometimes see the zodiacal light along the northern horizon in Connecticut, but he made no observations to test his theory. In 1905 Professor NEWCOMB³ observed the zodiacal light to a distance of 35° north of the Sun; and Professor BARNARD⁴ says he has at times seen a faint glow in the summer along the northern horizon at the Yerkes Observatory. So far as the writer has been able to determine these are the only other observations of this nature.

MT. HAMILTON, November 6, 1908.

¹ *Observations of the Zodiacal Light*, Vol. III of the Report on the United States Japan Expedition, 1856.

² *Silliman's Journal of Science*, **30**, 331, 1840.

³ *Astrophysical Journal*, **22**, 209, 1905.

⁴ *Astrophysical Journal*, **23**, 168, 1906.